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Final Technical Report for NASA Grant NAG5-1694
Cooperative Research in Terrestrial Planetary
Geology and Geophysics

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This grant covered the period from July 1991 through August 1994. The research covered a number of topics and studied the Earth and Mars.

1. Earth Studies work stressed interpretation of MAGSAT crustal magnetic anomalies to determine the geologic structure, mineralogical composition, magnetic nature and history of submarine features. Work was also done in the area of terrestrial remote sensing.
2. Mars research included work on the early evolution of the Martian atmosphere and hydrosphere as well as investigations of large impact basins on Mars.

Detailed summaries of the research done are attached.

III. Current Research Efforts

Research has been done in several areas including earth studies and planetary science. Details are given in the following as well as a list of publications which resulted from this work.

1. Earth Studies

James H. Roark has worked on a study of the Earth's crustal structure and evolution.

This project entails geophysical research and computer modeling of MAGSAT crustal magnetic anomalies in order to determine the geologic structure, mineralogical composition, magnetic nature and history of submarine features. Basic research responsibilities included geophysical modeling, background and literature work, and training new personnel. Roark is now responsible for writing point and click modeling programs, data/scientific visualization programs and graphics output programs. He has also been requested to write data visualization and graphics output programs for other projects at NASA. This has involved use of UNIX, C, AVS, and IDL (interactive Data Language) programming on SUN spark workstations and CRAY/CONVEX super computers.

Much of the work involved modeling in the SW-Indian-Antarctic Ocean which showed evidence for a TRM (thermal remnant magnetization) contribution from KQZ (Cretaceous Quiet

Zone) crust. This modeling also helped constrain the geographical extent of the KQZ crust, the amount of TRM, and the nature of poorly understood plateaus off the coast of Antarctica.

Modeling of the Crozet Plateau showed how magnetization structure could be used to identify a different origin for two adjacent oceanic structures.

Carla Evans has been working with the NASA Biospheric Sciences Branch. Her main task has been with the Boreal Ecosystems Atmospheric Study (BOREAS) project as a site liaison for Canada. The visits to the sites in Saskatchewan and Manitoba and a detailed search for geo-data. An intensive Canadian environmental process has been involved which required providing information necessary for their requirements. BOREAS, itself, is a study focussing on the interactions between the boreal forest biome and the atmosphere to clarify their roles in global change. It is an international cooperative field experiment integrating land surface climatology, tropospheric chemistry and terrestrial ecology, with remote sensing playing an integrating role.

Evans has also been involved in geological research primarily consisting of developing a catalog of references to Mima Mound terrain in order to document locations to test a seismic hypothesis of origin.

Stephanie Thliveris-Harrison has worked on MAGSAT data and SEASAT/GEOSAT data. The MAGSAT project involved modeling crustal magnetic RTP anomalies over passive margins and continental rift zones concentrating on the Australian Bight region. A consortium of seismic data has been acquired and several working models have been produced using IDL graphics on the SUN/UNIX system. The current model will be refined focusing on problems associated with scalar/RTP data sets and high heat flow values measured in southeastern Australia.

Thliveris-Harrison has done a comparative analysis between SEASAT/GEOSAT overland radar altimetry data and corresponding topographic data. The SEASAT/GEOSAT data has been used for comparative work in several regions around the world (Sudan, Egypt, South America) focusing recent efforts specifically on the Colorado plateau.

Thliveris-Harrison took part in the Mars Observer thermal vacuum tests conducted at GE-Astro in New Jersey. She was involved in monitoring the SEPETT test operations related to the Thermal Emission Spectrometer.

Wolfe also continued work with S. Walter on a book analyzing the applications of satellite technology to disaster management. Tasks include searching for applicable detailed information, collecting a large "source" bibliography and reviewing various articles and papers. Important work is being done with digital image data (SPOT1, 10 meter resolution; Landsat) to ascertain its utility in delineating small features such as buildings which may or may not be altered by catastrophic events such as earthquakes, volcanic eruptions and so forth.

Other aspects of disaster mitigation that are being considered include the prediction of catastrophic events, timely warnings of impending danger, search and rescue in the aftermath, communications (a very important priority), medical care and, most importantly, the logistical support and coordination for all of these efforts including outside humanitarian relief.

2. Mars Studies

Martha Schaefer has continued work on modelling the evolution of the Martian atmosphere and hydrosphere. The preliminary model was modified from being a steady-state model, to one that is time-varying. The method used to attack the problem was the kinetic method, which has been applied to terrestrial systems in recent years with much success. This method, which treats geochemical cycles as systems of complex geochemical reactions, is capable of elegantly handling the interactions between simultaneous chemical reactions needed to understand such a complicated system. Work on this model was presented at the Workshop on the Martian Surface and Atmosphere Through Time, in Boulder, CO, September 1991.

The second research topic concerns volcanic recycling of carbonates. Decomposition of carbonates under turbulently-flowing lava holds great promise as mechanism for resupplying the atmosphere of Mars with carbon dioxide. Terrestrial komatiites, a reasonable analogy for Martian lavas, have been found to significantly erode the rocks over which they flow. Initial modelling of this process indicates that a hot, high-volume lava flow is capable of eroding several meters of carbonates in a day. If this process occurred over a large area for even a hundred days, large amounts of carbon dioxide could be injected back into the Martian atmosphere essentially instantaneously.

Charles H. Wolfe continued work with H.V. Frey (GSFC) on the origins of the Martian Crustal Dichotomy. This involves the search for large "Impact Basins" and "Basin Rings" associated with these features.

In the search for multiple ring impact basins in the southern hemisphere of Mars, evidence was found for a large (@ 600 km inner diameter) and previously unknown impact basin that is centered southwest of the Hellas impact feature near Malea Planitia. Geologic features such as "Mountain" units, Noachian etched plains units, massifs and linear features (e.g. faults, ridges and channels) among others, appear to be arranged, both concentrically and radially, around a central point at approximately 328 degrees W, 66 degrees S. A closer look at the area of this possible basin (Malea) has revealed evidence for yet another impact basin in the region south of Malea. The evidence for both of these basins is compelling.

The geomorphology of the southern hemisphere, particularly in this region, is quite chaotic. A possible explanation for this amalgamation of terrain is that the area has been influenced by impact mechanics from Hellas, South Polar and the two newly proposed impact basins. A search continue for new features using Viking and Mariner digital data as well as USGS photomosaics in order to gain a better understanding of the geology and geomorphology of the region with respect to the Martian crustal dichotomy.

3. Publications

Roark, J., and Fullerton, L., Frey, H., Thomas, H., Modeling of MAGSAT RTP Regional Crustal Magnetic Anomalies in the SW — Indian-Antarctic Ocean, (abstract, oral presentation), EOS Trans. AGU, 72, No. 17, 1991.

Frey, H., and Roark, J., Diverse Origins of the Crozet Bank and Del Cano Rise (SW Indian Ocean) from MAGSAT Crustal Anomaly Data, (being revised for JGR).

Harrison, S., and Roark, J., Frey, H., MAGSAT Crustal Magnetic Anomalies at Passive Margins: The Australian Bight Anomaly, (abstract in press for Spring AGU conference)

Blodget, H.W., Taylor, P.T., and Roark, J.H., Shoreline changes along the Rosetta-Nile Promontory: Monitoring with satellite observations, Marine Geology, Vol. 99, pg. 67-77, 1991.

IV. Future Efforts

It is anticipated that research will continue in many of the same areas as were covered in the past 12 months. Details of the proposed efforts in the various areas follows.

1. Earth Studies

i) Interpretation of MAGSAT crustal magnetic anomalies (Harrison, Roark, Fullerton).

Additional areas in the Indian-Antarctic Ocean in which remanent magnetization combines with induced/viscous magnetization will be studied. Forward modeling will be used to separate the different contributions, and the extent of amplitude of the remanent contribution will be used to constrain tectonic models of the oceanic crust. The area surrounding Australia will be studied first, in conjunction with the passive margin work already underway.

Modeling of the MAGSAT signature around the passive margins of Australia will be completed in order to determine the magnetization contrast between the continental and ocean crust. For the southern margin, a small Cretaceous Quiet Zone adds further complications in that remanence may be contributing to the satellite-elevation anomaly.

A new model of the Ontong-Java Plateau will be completed in order to assess to what extent the MAGSAT data can constrain the still-controversial nature of this feature. This feature was previously modeled but with lower resolution POGO data; the improved resolution of MAGSAT should make possible the separation of contributions from the Plateau and the nearby convergence zone against which the plateau lies.

ii) GEOSAT Overland Altimetry (Harrison)

A blind test of the automated procedure for extracting river water levels over time will be done. Comparison of continental scale topography from combined SEASAT and GEOSAT altimeter data with surface data will continue in order to assess the quality of the satellite data in regions with different surface slopes and surface characteristics. Preliminary assessment of overland altimetry from TOPEX will begin by comparison with surface data as well as with existing satellite altimetry data, where profiles from the different spacecraft crossover one another.

2. Mars Studies

i) Martian geologic studies (Wolfe, Roark,, part-time students)

Work will continue in several areas. The search for evidence of ancient and degraded impact basins will shift from the south polar reign to the northern lowlands and Tharsis regions. The young plains and volcanic features in these areas makes difficult the identification of ancient structures, but inclusion of recently available higher resolution gravity data from a new GSFC model will help.

Forward modeling of the known impact basins, using a three-dimensional Gaussian quadrature program derived from MAGSAT modeling studies, will be used to constrain the density structure below these basins, and to infer the degree of compensation and evolution of the lithosphere during the period of basin formation. The new GSFC gravity model will be the basis for comparison.

Detailed studies of the age of apparently old ridged plains which were likely resurfaced in the middle portion of Mars history will shift from the Malea Planum region to outcrops in Cimmeria Terra. The origin of these volcanic plains is uncertain; they are not obviously associated with any larger impact basin as appears to be the case in Malea. Their age will be important in assessing the volcanic history of Mars and helping to decide between alternative models (punctuated or secularly declining volcanism).

Photogeologic mapping along the dichotomy boundary in the Phaetontis region will complete the detailed study along the well-exposed parts of this fundamental crustal feature. Detailed stratigraphy and relative resurfacing ages will be determined and compared to those in other parts of the country.

ii) Mars Evolution Martha Schaefer will continue research efforts on the modelling the evolution of the Martian atmosphere and hydrosphere. Particular attention will be paid to the cycling of carbon dioxide between the atmosphere and carbonates.

A Joint
NASA/Goddard Space Flight Center — University of Maryland
Cooperative Research Program in Terrestrial and Planetary
Geology and Geophysics

Introduction

A cooperative research agreement currently exists between the Astronomy Department of the University of Maryland and the Laboratory for Terrestrial Physics of the NASA Goddard Space Flight Center. Under this agreement, funding has been provided for both long and short term appointments for persons involved in research projects of mutual interest to the scientific staffs of the two institutions. These projects cover a fairly broad range of topics and are discussed in detail in the body of this proposal. The current proposal asks for a continuation of this program.

Recent Progress

Investigations of Crustal Structure and Evolution Using MAGSAT Crustal Magnetic Anomaly Data

James Roark worked on geophysical research and computer modeling of MAGSAT crustal magnetic anomalies in order to determine the geologic structure, mineralogical composition, magnetic nature and history of submarine features. He recently published seismic refraction models from KRISP studies of the East African Rift, which provide important constraints on the origin of MAGSAT crustal magnetic anomalies. These constraints were used to model the rift to help determine its crustal magnetic structure. It was determined that some combination of (a) higher heat flow producing greater thinning of the magnetic crust in the north, (b) higher than usual susceptibility of the upper layer for granitic composition (*e.g.*, due to the presence of dikes), and/or (c) variable magnetization contribution from rift volcanics may be necessary to explain the observed MAGSAT anomalies.

In an effort to study both the large-scale magnetization contrast between the continental and oceanic crust as well as within the continental crust he has been involved in constructing forward models of magnetic anomalies over Australia and its surroundings. Susceptibility values required to reproduce the MAGSAT anomaly pattern lie in the range of 0.0008 to 0.00220 (cgs). Crustal thickness variations appear to play a major role in explaining the anomaly pattern, but in some regions it appears that strong crustal susceptibility contrasts are more important.

Stephanie Thliveris-Harrison has continued MAGSAT work on modeling of the Australian continent and passive margins during much of the past year. This work involves collecting and analyzing seismic, geothermal, and lithological data for continental Australia with the final computation of a crustal magnetic model(s). She gave an oral presentation of this work at the University of Maryland, Astronomy Department and at the American Geophysical Union: Spring, 1993. She has continued to work with IDL/graphics on the Sun/UNIX system, which has made it possible to produce graphics of various models.

Mars Studies

During the past year, Martha Schaefer has been preparing for the data anticipated to be arriving this fall from the Mars Observer Laser Altimeter (MOLA). She has been working with Maria Zuber at Goddard to modify some of her geophysical modelling programs to run on a Unix workstation, and output results in an easily-interpretable graphical form.

She is also starting a new topic of research, that of topographic analysis of Martian landforms. Currently she is involved in developing the necessary software on the workstation for geomorphic analysis of Martian landforms using the topographic data from MOLA.

Charles Wolfe has worked with Herb Frey on a detailed analysis of the Lunae Planum region in the western hemisphere of Mars. This was done to better constrain resurfacing events in this area relative to the Martian geologic time scale and also to determine based on superposition analysis of craters, if the Lunae Planum indeed represents a standard production population of impact craters.

For some time Lunae Planum has been regarded as a standard production surface for impact craters and therefore should represent a reasonably good record of the cratering history of the planet over some time period. One would expect, given this, to find a random distribution of craters of all sizes. However, the random nature of impacts, over this roughly 1.1 million square kilometer area, seems to break down at certain crater diameters across the Lunae Planum. This may be indicative of resurfacing events that have occurred in Lunae Planum at different times throughout Martian history thus affecting estimates of impact crater production over time as well as age estimates for different surfaces elsewhere on Mars. Work is underway to address this issue and will continue throughout next year.

Wolfe and Frey are also looking at the Xanthe Terra region on Mars to determine if it is the site of yet another large, possibly multi-ring, impact basin. This work will further the search for large impact basins on Mars and help to provide insights into the geomorphologic and structural origins of this area. Effects related to the crustal dichotomy will also be studied.

Terrestrial Remote Sensing and Field Studies

Carla Evans has completed work on a project on the study of Mima Mound formations. This involved satellite image analysis as well as a statistical analysis of seismic and feature locations. A report on this work was presented at the American Institute of Biological Sciences Conference in August 1992. Several publications are completed or in preparation.

She is also involved in a project on studies of the Aral Sea Basin. This involved an analysis of remote sensing data on the area and some work was reported on at the March 1993 International Symposium on Remote Sensing and Global Environmental Change.

More recently, Ms. Evans has become involved in the BOREAS Project (BOReal Ecosystems Atmosphere Study). This is a joint U.S. and Canadian study and will include terrestrial ecology, hydrology, land surface climatology, trace gas biochemistry, atmospheric chemistry, boundary layer meteorology, energy and water fluxes, satellite data analysis and integrative modelling. Her current work involves organizing and coordinating all activities relating to the selection of sites in which research towers are to be constructed. These sites are at two study areas in Saskatchewan and Manitoba Canada. She also provides information about the sites for the Canadian environmental review process in a report. Over 100 international scientific research projects have been accepted that will be interactively involved during the IFC's. She is also involved with helping these investigators to find study areas for their specific scientific needs.

Penny Masuoka completed the calibration of TM and SPOT data for 56 test sites near Kursk, Russia as part of the research being done for the KUREX project. KUREX was a joint Russian/U.S. field experiment that took place in the summer of 1991. Concurrent satellite and aircraft overflights were made during the field experiment as well as a number of ground-based remote sensing, weather, soil and biomass measurements. The TM and SPOT calibrated data will be atmospherically corrected and then compared to biomass data.

Computer Support

Masuoka has also worked with Martha Schaefer to study ways to analyze laser altimeter data and compare it to other data formats such as image, DEM, and map data. Analyzing laser altimeter data with other data sets is a challenge due to its different format, a straight line of data points. They are currently considering 2 commercial software packages, an image processing package with some GIS capability and a GIS package. The GIS and image processing capabilities of these 2 packages are being studied to determine their suitability to process and analyze the diverse data types for this research.

Dr. Schaefer also acts as system administrator for a network of seven Sun workstations. This involves maintaining the machines, helping determine present and future software and hardware needs, and assisting users as necessary.

Publications in the Last Year

Christensen, P. R., S. T. Harrison, P. Barbara, and S. Ruff, 1993. Thermal-Infrared Emission Spectroscopy of Natural Surfaces: Application to Coated Surfaces *Lunar and Planetary Science XXIV*, 287-288.

Christensen, P. R. and S. T. Harrison, 1993. Thermal Infrared Emission Spectroscopy of Natural Surfaces: Application to Desert Varnish Coatings on Rocks, *Journal of Geophysical Research*, in press.

Frey, H., B. Bills, W. Kiefer, S. Nerem, J. Roark, and M. Zuber, 1993. Free-Air and Bouguer Gravity Anomalies and the Martian Crustal Dichotomy, *Lunar and Planetary Science XXIV*, 511-512.

Frey, H., B. Bills, W. Kiefer, S. Nerem, J. Roark, and M. Zuber, 1993. New Mars Free-Air and Bouguer Gravity: Correlation with Topography, Geology and Large Impact Basins, *Lunar and Planetary Science XXIV*, p. 513-514.

Fullerton, L., H. Frey, J. Roark, and H. Thomas, Evidence for a Cretaceous Quiet Zone NRM Contribution to MAGSAT Data over Conjugate Features in the Southwest Indian Ocean, (in preparation).

Kiefer, W., B. Bills, H. Frey, S. Nerem, J. Roark, and M. Zuber, 1993. An Inversion of Geoid and Topography for Mantle and Crustal Structure on Mars, *Lunar and Planetary Science XXIV*, 797-798.

Roark, J., H. Frey, H. Thomas, Crustal Structure in the East African Rift and MAGSAT Crustal Magnetic Anomalies, 1992. *EOS Trans. AGU*, 73, No. 43, p. 140.

Thliveris-Harrison, S., J. Roark, H. Frey, and H. Thomas, 1993. MAGSAT Crustal Magnetic Anomalies over Australia and Surroundings: Continental Scale Modeling, *EOS Trans. AGU*, bf 74, No. 16, p. 111.

Schaefer, M. W., 1993. Local topography of Mars and its relationship to surface weathering processes, *Lunar and Planetary Science XXIV*, pp. 1243-1244.

Zuber, M., B. Bills, H. Frey, W. Kiefer, S. Nerem, and J. Roark, 1993. Possible Flexural Signatures around Olympus and Ascraeus Montes, Mars, *Lunar and Planetary Science XXIV*, 1591-1592.

Proposed Work in the Coming Year

It is anticipated that research will continue in many of the same areas as were covered in the past 12 months. In addition, some new efforts are being added. Details of the proposed efforts in the various areas follows.

Terrestrial Gravity and Magnetism Studies (Roark, Thliveris-Harrison, Hourly Personnel)

MAGSAT Crustal Anomalies: Crustal Magnetism at Plate Margins

The major objectives of this work are to utilize MAGSAT data to (1) determine the structure, nature, and tectonic evolution of submarine plateaus, (2) assess the role of thermal remanent magnetization in MAGSAT oceanic anomalies, (3) understand the variable MAGSAT signature at passive margins in terms of the crustal structure of these margins, and (4) assess the role of thermal enhancement of viscous magnetization in downgoing slabs at subduction zones. Another objective is to model the expected resolution improvement in GAMES-elevation data.

In the next year, we will complete the modeling of the passive margins around Australia. The model results for the conjugate plateaus in the southwest Indian-Antarctic Ocean will be published. We will study the thermal structure beneath the Conrad Rise, where structure seems to play almost no role in the MAGSAT anomaly, but where TRM is important. A study will be started of the Falkland Plateau and other "continental" fragments for comparison with the Agulhas Plateau model already completed. We will also compute GAMES-elevation (275 km) versions of all MAGSAT-elevation models to assess expected improvement in resolution and discriminability between models.

Geopotential Fields Modeling and Simulations Related to the GAMES (Gravity And Magnetism Experiment Satellite) Mission

One of the main objectives of the MAGSAT mission studies has been the use of these satellite data to interpret and define lithospheric structure and information. Because satellite data are, of their very nature, global in character, they will aid us in making geologic maps that cover the Earth. Because magnetic anomaly studies utilizing satellite measurements are a very recent activity we have extended our work to include collaboration with other Earth scientists pursuing similar research efforts (at such institutions as Purdue, SIU, OSU, and Cornell). These joint projects have proven to be very beneficial to our understanding of the sources for the MAGSAT data. Such studies will continue and we plan to extend them to other researchers as well.

The present study includes several directions of geopotential fields evaluation. First, we will assess our ability to utilize the expected gravity and magnetic anomaly field to resolve

distinct and known geologic/tectonic units. Previously, theoretical simulations indicated a threefold increase in magnetic anomaly resolution of GAMES over MAGSAT. We will evaluate this increase in anomaly resolution and how it may be used to describe structures in Earth's crust. Second, we will investigate the benefits of measuring both gravity and magnetic fields with the same spatial positions.

In the upcoming year, we will obtain complete and up-to-date ground-based digital gravity and magnetic data sets. These will be upward continued to the GAMES altitude and used to simulate our expected geopotential data sets. The simulated data sets will then be used to evaluate the nature and type of geologic/tectonic structures we could expect to detect with GAMES. Because GAMES will have an orbit significantly different from previous geopotential field missions we will investigate new methods and techniques for data reduction, analysis, presentation, and noise elimination. These results will be presented at scientific meetings and submitted to appropriate journals; this will introduce the Earth Science community to the proposed GAMES mission.

Early Mars: Impact Basins, Crustal Dichotomy and Volcanic Resurfacing (Roark, Wolfe, Reidy, Hourly Personnel)

Crustal Dichotomy and Dichotomy Boundary

We will complete in the first year a detailed structural and stratigraphic study of the crustal dichotomy boundary in western Acidalia, as a complement to that already done in Ismenius Lacus (Dimitriou, 1990a,b) and for comparison with studies already done further east (McGill and Dimitriou, 1990; Maxwell and McGill, 1988; Frey et al., 1988a). The goal is to determine why the topography/physiography/geophysical relations in SE Acidalia/Western Arabia are so different from that further east, whether this portion of the dichotomy and dichotomy boundary is more likely due to endogenic or exogenic causes, and to compare the deformational and resurfacing history of this area with other portions of the boundary. An important objective is to determine, from the cumulative frequency curves, the timing of major resurfacing events, the efficiency of these events in burying older surfaces, the role of topography in this efficiency, and the time the original and final topographic dichotomy was established here and further east. Direct comparison of the Acidalia region with the Ismenius Lacus and Amenthes-Aeolis areas will be done to compare the deformational history and its possible variation along the boundary.

The newly available geophysical data (Smith et al., 1993) will be used to construct simple models of the variation in crustal structure across the dichotomy boundary, and how this varies along the boundary. The Bouguer gravity signature shows considerable variation along the boundary, with changes often but not always in concert with structural changes (Frey et al., 1993a). The Bouguer gravity across the boundary seems more consistent, with a change of 200 milligals from negative over cratered terrain to positive (or at least relatively more positive) over the lowlying plains (Frey et al., 1993a,b). We propose both inversion and forward modeling, in collaboration with Walter Kiefer. Kiefer has already produced

preliminary models of crustal thickness variations for Mars based on the new gravity model (Kiefer et al., 1993). Forward modeling will be based on existing programs available at Goddard which have been used by the PI in studies of satellite-derived geophysical data for the Earth. Constraints on these models will include the obvious geological and structural data, and topographic data. Although we will begin this effort in the first year, it is expected that the bulk of this will be accomplished in the second and third year, using improved topography and gravity data when it is freely available.

Large Multi-ring Impact Basins on Mars

In the coming year we will submit for publication the results of our search for evidence of large impact basins in the south polar region, and the implications of the basins we found for influencing the distribution of polar deposits and structures (Reidy and Frey, 1993).

We will continue our mapping and study of the Chryse/Acidalia Basin region (related to (a) above), in order to determine how strong is the evidence that the topographic low in Chryse has moved over time from that due to the impact to that associated with later filling (Stockman and Frey, 1993). The structural and topographic evidence for the Acidalia Basin will be documented. The apparent influence of the Acidalia Basin on the evolution of the Chryse Basin (Craddock et al., 1993) will be studied, through reconstruction of basin rings and analysis of superposition relations, as another example (along with Malea B/Hellas) of the role of basin overlap, and the relation of these two basins to the development of the crustal dichotomy and evolution of the dichotomy boundary in western Mars will be investigated as part of (a) above.

In collaboration with Walter Kiefer (USRA/LPI) we will use the newly available geophysical data to model the positive Bouguer gravity anomalies seen in the larger basins (Frey et al., 1993b). The anomalies will be modeled both in terms of crustal thinning and mantle uplift, and in terms of basin filling (mascons). Constraints on the latter are provided in some cases by nearly buried old craters (Hellas, Argyre) or impact basin rims (northern Isidis rim). Implications for basin evolution will be studied, both individually and as a function of basin size and age. This work will take place largely in the second and third year, after the Chryse/Acidalia study is complete, but early models of Hellas, Argyre, Utopia and Isidis will be started in the first year.

Major Resurfacing Events in Martian History

In the coming year we will complete the study of the resurfacing history of the Malea Planum region, which lies in the overlap of the Malea and Hellas Basins (Frey et al., 1991b; Reidy et al., 1992). Both age and thicknesses of materials associated with major resurfacing events will be determined and compared with our earlier results for Nplr and Hr units in Memnonia and Argyre, Lunae Planum, Tempe Terra and elsewhere. Because of the uncertainty about crater production curves, which we address below, this study will be done differentially by comparison with Lunae Planum.

In the first and second years we propose a re-examination of the crater production curve controversy by examining first the distribution of craters in given counting areas as a function of diameter. We have a large library of crater counts from a variety of surfaces, including old cratered terrain in eastern and western Mars, ridged plains in Lunae Planum, Coprates and Malea, and smooth plains units north of the dichotomy boundary and elsewhere ((Frey et al., 1988; Frey and Grant, 1990; Grant and Frey, 1987; Frey and Grant, 1989; Frey et al., 1987, 1989, 1991a). For selected regions the distribution of craters of different sizes will be plotted to determine which diameters appear to be significantly depopulated (spatially), and then compared to resurfacing branches derived from the Neukum and Hiller (1981) and Neukum (1983) curves to see which if either of these curves better indicates the diameters most affected by depopulation. Areas with uniform distribution of craters over large size ranges can be used to approximate production surfaces if these craters are superimposed on the terrain. By studying a number of such regions it may be possible to synthesize a better "standard production curve" that represents more crater production than crater destruction. If we are able to synthesize such a curve, we will compare it to the existing "production" curves, an re-assess if necessary the number and timing of resurfacing events those other curves imply.

Terrestrial Remote Sensing and Field Studies (Evans, Schaefer, Graduate Assistant)

Work on the remote sensing of degradation in the Aral Sea Basin will continue. This will involve analysis of satellite data and ancillary information.

The BOREAS project is an international project intended to improve our understanding of the interactions of the boreal forest biome and the atmosphere in order to clarify their roles in global change. In the upcoming year several field expeditions will be organized to collect ground data on the boreal forest in Canada. In addition to the field experiments, satellite and other digital data will be analyzed. Results of this project will be published in appropriate journals and reports.

Work will continue on the development of the data system for terrestrial laser altimetry. A graphical user interface will be developed, to enable the data to be accessed and displayed in an intuitive manner. Existing data from previous field experiments, as well as data from a new field experiment, will be incorporated into the system and the results analyzed.

Image Processing, GIS, and Computer System Support (Masuoka, Schaefer)

This task comprises computer system support, as well as research into how image processing, GIS (Geographic Information System) and visualization software packages are used in remote sensing research and how the three types of packages could be more effectively used together.

Specific topics being studied include:

- a graphical user interface linking together the major functions from the 3 packages to provide scientists with a tool to use the capabilities from the packages without having to learn the packages,
- a study of the current state of image processing software and what types of image processing programs are now available,
- a study of software that could be developed to facilitate the use of the 3 software packages for remote sensing (such as, software to convert images between the 3 formats), and
- a study of the use of image processing software in conjunction with GIS software and how it can be used most effectively in remote sensing research.

A critical element to the research being done above is user assistance and training. This "support" work provides numerous opportunities for seeing how image processing, GIS, and visualization software are being used in various remote sensing fields and provides opportunities to study better ways to use the packages together.

The network of workstations in the Geodynamics Branch will continue to be administered by Dr. Schaefer.

Mars Observer Laser Altimeter Data Analysis (Schaefer, Roark, Reidy, Hourly Personnel)

Work currently in progress on software development in preparation for the flood of data expected from the Mars Observer Laser Altimeter (MOLA) will be continued. This software will primarily be used for the display of the data, although some geomorphic analysis software is under development also.

When data begins arriving (late in the fall of 1993), processing and analysis of the data will commence. Topics to be studied include: (1) the relationship between the gravity and topography fields and what this can tell us about the structure of the subsurface of Mars; (2) geomorphology of surface features on Mars, including craters, valleys, and small-scale enigmatic features, and what this can tell us about the history of the climate and surface processes on Mars.

Volcanology: Physical Modelling and Remote Sensing (Research Associates)

This new task will be in the area of volcanology, both in physical modelling and in remote sensing of climatologically-important gases. Specific topics to be studied include the

dynamics of explosive eruptive plumes, concentrating on understanding the physical parameters that affect plume rise, and lava flow dynamics. Volcanic plumes also will be studied as sources for climatologically-important gases. Remote sensing studies will focus on shortwavelength infrared data on extremely high temperature volcanic phenomena. Both the plume work and the high temperature studies will use ground-based, aircraft, and orbital remote sensing data. Also included will be geologic mapping of terrestrial and extraterrestrial lava flows.

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Scientific and Technical Personnel

The principal investigator, Martha W. Schaefer, holds the position of Assistant Research Scientist in the Astronomy Department of the University of Maryland at College Park. She received S.B. degrees in Physics and in Earth and Planetary Sciences from M.I.T. in 1979, and a PhD in Planetary Sciences from M.I.T. in 1983. Before coming to the University of Maryland she held positions at the Geophysical Laboratory of the Carnegie Institution of Washington and at the Naval Research Laboratory. Her published research includes a wide variety of topics, from crystal chemistry and mineralogy, to high-pressure studies and solid state physics, to planetary astronomy and Martian geochemistry and geomorphology. She is also co-author of an undergraduate planetary science textbook to be published later this year.

The co-investigator, John Trasco, is currently the Associate Director in the Department of Astronomy at the University of Maryland at College Park. He received his B.S. in Physics from Fordham University in 1963 and his Ph.D. in Astronomy from Columbia University in 1969. Before coming to the University of Maryland, he held a faculty position at the University of Virginia. He has done research in the area of stellar structure and atmospheres. His current responsibilities include oversight of the instructional program in the Department of Astronomy.

Administrative and Detailed Budgetary Information

This project will be administered through the University of Maryland at College Park, Astronomy Department.

III. Current Research Efforts

Research has been done in several areas including earth studies and planetary science. Details are given in the following as well as a list of publications which resulted from this work.

1. Earth Studies

James H. Roark has worked on a study of the Earth's crustal structure and evolution.

This project entails geophysical research and computer modeling of MAGSAT crustal magnetic anomalies in order to determine the geologic structure, mineralogical composition, magnetic nature and history of submarine features. Basic research responsibilities included geophysical modeling, background and literature work, and training new personnel. Roark is now responsible for writing point and click modeling programs, data/scientific visualization programs and graphics output programs. He has also been requested to write data visualization and graphics output programs for other projects at NASA. This has involved use of UNIX, C, AVS, and IDL (interactive Data Language) programing on SUN spark workstations and CRAY/CONVEX super computers.

Much of the work involved modeling in the SW-Indian-Antarctic Ocean which showed evidence for a TRM (thermal remnant magnetization) contribution from KQZ (Cretaceous Quiet

Zone) crust. This modeling also helped constrain the geographical extent of the KQZ crust, the amount of TRM, and the nature of poorly understood plateaus off the coast of Antarctica.

Modeling of the Crozet Plateau showed how magnetization structure could be used to identify a different origin for two adjacent oceanic structures.

Carla Evans has been working with the NASA Biospheric Sciences Branch. Her main task has been with the Boreal Ecosystems Atmospheric Study (BOREAS) project as a site liaison for Canada. The visits to the sites in Saskatchewan and Manitoba and a detailed search for geo-data. An intensive Canadian environmental process has been involved which required providing information necessary for their requirements. BOREAS, itself, is a study focussing on the interactions between the boreal forest biome and the atmosphere to clarify their roles in global change. It is an international cooperative field experiment integrating land surface climatology, tropospheric chemistry and terrestrial ecology, with remote sensing playing an integrating role.

Evans has also been involved in geological research primarily consisting of developing a catalog of references to Mima Mound terrain in order to document locations to test a seismic hypothesis of origin.

Stephanie Thliveris-Harrison has worked on MAGSAT data and SEASAT/GEOSAT data. The MAGSAT project involved modeling crustal magnetic RTP anomalies over passive margins and continental rift zones concentrating on the Australian Bight region. A consortium of seismic data has been acquired and several working models have been produced using IDL graphics on the SUN/UNIX system. The current model will be refined focusing on problems associated with scalar/RTP data sets and high heat flow values measured in southeastern Australia.

Thliveris-Harrison has done a comparative analysis between SEASAT/GEOSAT overland radar altimetry data and corresponding topographic data. The SEASAT/GEOSAT data has been used for comparative work in several regions around the world (Sudan, Egypt, South America) focusing recent efforts specifically on the Colorado plateau.

Thliveris-Harrison took part in the Mars Observer thermal vacuum tests conducted at GE-Astro in New Jersey. She was involved in monitoring the SEPETT test operations related to the Thermal Emission Spectrometer.

Wolfe also continued work with S. Walter on a book analyzing the applications of satellite technology to disaster management. Tasks include searching for applicable detailed information, collecting a large "source" bibliography and reviewing various articles and papers. Important work is being done with digital image data (SPOT1, 10 meter resolution; Landsat) to ascertain its utility in delineating small features such as buildings which may or may not be altered by catastrophic events such as earthquakes, volcanic eruptions and so forth.

Other aspects of disaster mitigation that are being considered include the prediction of catastrophic events, timely warnings of impending danger, search and rescue in the aftermath, communications (a very important priority), medical care and, most importantly, the logistical support and coordination for all of these efforts including outside humanitarian relief.

2. Mars Studies

Martha Schaefer has continued work on modelling the evolution of the Martian atmosphere and hydrosphere. The preliminary model was modified from being a steady-state model, to one that is time-varying. The method used to attack the problem was the kinetic method, which has been applied to terrestrial systems in recent years with much success. This method, which treats geochemical cycles as systems of complex geochemical reactions, is capable of elegantly handling the interactions between simultaneous chemical reactions needed to understand such a complicated system. Work on this model was presented at the Workshop on the Martian Surface and Atmosphere Through Time, in Boulder, CO, September 1991.

The second research topic concerns volcanic recycling of carbonates. Decomposition of carbonates under turbulently-flowing lava holds great promise as mechanism for resupplying the atmosphere of Mars with carbon dioxide. Terrestrial komatiites, a reasonable analogy for Martian lavas, have been found to significantly erode the rocks over which they flow. Initial modelling of this process indicates that a hot, high-volume lava flow is capable of eroding several meters of carbonates in a day. If this process occurred over a large area for even a hundred days, large amounts of carbon dioxide could be injected back into the Martian atmosphere essentially instantaneously.

Charles H. Wolfe continued work with H.V. Frey (GSFC) on the origins of the Martian Crustal Dichotomy. This involves the search for large "Impact Basins" and "Basin Rings" associated with these features.

In the search for multiple ring impact basins in the southern hemisphere of Mars, evidence was found for a large (@ 600 km inner diameter) and previously unknown impact basin that is centered southwest of the Hellas impact feature near Malea Planitia. Geologic features such as "Mountain" units, Noachian etched plains units, massifs and linear features (e.g. faults, ridges and channels) among others, appear to be arranged, both concentrically and radially, around a central point at approximately 328 degrees W, 66 degrees S. A closer look at the area of this possible basin (Malea) has revealed evidence for yet another impact basin in the region south of Malea. The evidence for both of these basins is compelling.

The geomorphology of the southern hemisphere, particularly in this region, is quite chaotic. A possible explanation for this amalgamation of terrain is that the area has been influenced by impact mechanics from Hellas, South Polar and the two newly proposed impact basins. A search continue for new features using Viking and Mariner digital data as well as USGS photomosaics in order to gain a better understanding of the geology and geomorphology of the region with respect to the Martian crustal dichotomy.

3. Publications

Roark, J., and Fullerton, L., Frey, H., Thomas, H., Modeling of MAGSAT RTP Regional Crustal Magnetic Anomalies in the SW — Indian-Antarctic Ocean, (abstract, oral presentation), EOS Trans. AGU, 72, No. 17, 1991.

Frey, H., and Roark, J., Diverse Origins of the Crozet Bank and Del Cano Rise (SW Indian Ocean) from MAGSAT Crustal Anomaly Data, (being revised for JGR).

Harrison, S., and Roark, J., Frey, H., MAGSAT Crustal Magnetic Anomalies at Passive Margins: The Australian Bight Anomaly, (abstract in press for Spring AGU conference)

Blodget, H.W., Taylor, P.T., and Roark, J.H., Shoreline changes along the Rosetta-Nile Promontory: Monitoring with satellite observations, Marine Geology, Vol. 99, pg. 67-77, 1991.

IV. Future Efforts

It is anticipated that research will continue in many of the same areas as were covered in the past 12 months. Details of the proposed efforts in the various areas follows.

1. Earth Studies

i) Interpretation of MAGSAT crustal magnetic anomalies (Harrison, Roark, Fullerton).

Additional areas in the Indian-Antarctic Ocean in which remanent magnetization combines with induced/viscous magnetization will be studied. Forward modeling will be used to separate the different contributions, and the extent of amplitude of the remanent contribution will be used to constrain tectonic models of the oceanic crust. The area surrounding Australia will be studied first, in conjunction with the passive margin work already underway.

Modeling of the MAGSAT signature around the passive margins of Australia will be completed in order to determine the magnetization contrast between the continental and ocean crust. For the southern margin, a small Cretaceous Quiet Zone adds further complications in that remanence may be contributing to the satellite-elevation anomaly.

A new model of the Ontong-Java Plateau will be completed in order to assess to what extent the MAGSAT data can constrain the still-controversial nature of this feature. This feature was previously modeled but with lower resolution POGO data; the improved resolution of MAGSAT should make possible the separation of contributions from the Plateau and the nearby convergence zone against which the plateau lies.

ii) GEOSAT Overland Altimetry (Harrison)

A blind test of the automated procedure for extracting river water levels over time will be done. Comparison of continental scale topography from combined SEASAT and GEOSAT altimeter data with surface data will continue in order to assess the quality of the satellite data in regions with different surface slopes and surface characteristics. Preliminary assessment of overland altimetry from TOPEX will begin by comparison with surface data as well as with existing satellite altimetry data, where profiles from the different spacecraft crossover one another.

2. Mars Studies

i) Martian geologic studies (Wolfe, Roark,, part-time students)

Work will continue in several areas. The search for evidence of ancient and degraded impact basins will shift from the south polar reign to the northern lowlands and Tharsis regions. The young plains and volcanic features in these areas makes difficult the identification of ancient structures, but inclusion of recently available higher resolution gravity data from a new GSFC model will help.

Forward modeling of the known impact basins, using a three-dimensional Gaussian quadrature program derived from MAGSAT modeling studies, will be used to constrain the density structure below these basins, and to infer the degree of compensation and evolution of the lithosphere during the period of basin formation. The new GSFC gravity model will be the basis for comparison.

Detailed studies of the age of apparently old ridged plains which were likely resurfaced in the middle portion of Mars history will shift from the Malea Planum region to outcrops in Cimmeria Terra. The origin of these volcanic plains is uncertain; they are not obviously associated with any larger impact basin as appears to be the case in Malea. Their age will be important in assessing the volcanic history of Mars and helping to decide between alternative models (punctuated or secularly declining volcanism).

Photogeologic mapping along the dichotomy boundary in the Phaetontis region will complete the detailed study along the well-exposed parts of this fundamental crustal feature. Detailed stratigraphy and relative resurfacing ages will be determined and compared to those in other parts of the country.

ii) Mars Evolution Martha Schaefer will continue research efforts on the modelling the evolution of the Martian atmosphere and hydrosphere. Particular attention will be paid to the cycling of carbon dioxide between the atmosphere and carbonates.

Summary Report on NASA/Goddard Space Flight Center – University of Maryland Cooperative Research Program in Terrestrial and Planetary Geology and Geophysics

Publications

Effects due to overlapping large impact basins on Mars; Frey, Herbert, Reidy, Anne Marie, Roark, James H. and Stockman, Stephanie; LPSC XXV, 389-390, 1994.

Noachian and Hesperian modification of the original Chryse impact basin topography; Stockman, Stephanie, and Frey, Herbert; LPSC XXV, 1345-1346, 1994.

Contributions of Cretaceous Quiet Zone natural remanent magnetization to Magsat anomalies in the Southwest Indian Ocean; Lawrence G. Fullerton, Herbert V. Frey, James H. Roark, and Herman H. Thomas; Journal of Geophysical Research, Vol. 99, No. B6, Pages 11,923-11,936, June 10, 1994.

Noachian and Hesperian modification of the original Chryse impact basin topography; Stockman, Stephanie, and Frey, Herbert V.; Geophys. Res. Lett., accepted, 1995.

Early Mars: Impact Basins, Crustal Dichotomy, and Volcanic Resurfacing

Work continued on the study of large impact basins on Mars. Effects of overlap on impact basin structure and morphology were determined. The distribution of related volcanic features seems to be related to basin overlap, as does preservation of ancient terranes, and channel flow.

A new center and ring alignment for the Chryse impact basin was proposed based on photogeologic mapping and re-examination of the published geology. This work was presented at the Lunar and Planetary Science conference in 1994, and is the subject of a paper recently accepted by Geophysical Research Letters.

Terrestrial Gravity and Magnetism Studies

The MAGSAT group had a major publication in 1994 (see above). In this paper the Magsat magnetic anomalies over the Southwest Indian Ocean were modeled using a combination of induced plus viscous remanent magnetization. Models of conjugate

structures showed that induced plus viscous remanent magnetization models reproduces the Magsat anomalies associated with non-Cretaceous Quiet Zone crust and a dominant natural remanent magnetization component are required to explain the anomalies associated with Cretaceous Quiet Zone crust.

J. Roark also performed the following duties/accomplishments:

1. Computer software development and programming and systems support.

- (a). Wrote several IDL programs to display Mars gravity/topography and Earth topography data.
- (b). Used PCI software to enhance TM images of the Bolivian Andes.
- (c). Began learning UNIX system administration duties.
- (d). Installed cdmosaic and cdbrowse software used to view and mosaic Mars viking data.

S. Harrison's research continued to focus on forward modeling Magsat reduced-to-pole (RTP) crustal magnetic anomalies over the Australian continent and its southern passive margin (Australian Bight). The focus of this project changed during the course of the past year in that modeling procedures are approached differently (i.e. absolute modeling as opposed to modeling with a background) and larger surface areas are included. These changes are being incorporated into the current model.

Results from this work are being written up for publication.

Terrestrial Remote Sensing and Field Studies

BOREAS Project

The BOREAS (BOReal Ecosystem Atmosphere Study) Project conducted 5 sets of experiments in Canada from March - October each lasting from 3 - 5 weeks. C.S. Evans acted as the Study Area Manager for 3 of the experiments at the Southern Study Area in Candle Lake, Saskatchewan. This entailed managing the office staff of 5-6 persons and keeping track of over 200 scientists and field crews over a 100km X 100km area. In addition, support was given to the Mission Manager which included keeping track of the location of up to 10 aircraft surveying the study area. The remaining time back at the office was used to coordinate these remote activities

(logistics) and to provide science support to the Principal Investigators.

GSFC Distributed Active Archive Center (GDAAC) Educational Outreach Program

C. S. Evans was involved with the initial stage of coordinating a new Educational Outreach Program with Robin Bell in code 902.2 (Goddard DAAC). This new program has been established in order to provide a product containing the data available from the GDAAC that highschool, community college and undergraduate levels can use in the classroom. The first topic will be on the use of TOMS data for global ozone measurements and the product will be distributed on CDs. A working partnership has been established with the Univ.of Maryland Joint Educational Initiative (JEI) group. The first product is targeted to be completed by August 1995 for use in a JEI workshop.

Data System for Terrestrial Laser Altimetry

M. Schaefer developed a user-friendly data system for the analysis of terrestrial laser altimetry data. This system, written in IDL, enables the data to be accessed and displayed in an intuitive manner. It is extendable, and enables new subroutines for data display and analysis to be added easily.

Computer System Support

M. Schaefer administered the network of Sun workstations and X terminals in the Geodynamics Branch. She installed the upgraded CPU to the main server , and added more memory and disk space, enabling greater efficiency for the system.